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TIMELY DELIVERY OF POWER OUTAGE NOTIFICATIONS IN LOW-POWER AND LOSSY NETWORKS

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ABSTRACT

Techniques are described herein to timely deliver Power Outage Notification (PON) messages when a power outage occurs in smart utilities. Irrelevant packets may be proactively prevented by broadcasting the PON alert to notify the surrounding nodes, and may also be filtered and discarded when a node is experiencing an outage. Multiple PON packets may be intelligently aggregated and compressed.

DETAILED DESCRIPTION

Interoperable wireless mesh solutions are under development for smart utilities and smart cities applications, such as smart grid Advanced Metering Infrastructure (AMI) networks. One important application of AMI networks is reporting of Power Outage Notifications (PONs). Timely delivery of PONs allows a utility to efficiently identify and quickly react to the occurrence of a power outage. This is essential for optimizing utility operations, such as recording the power outage duration for future analysis, providing real-time feedback of the fieldwork, and preventing unnecessary truck rolls that may be triggered by PONs.

Figure 1 below illustrates an example power outage in a Low-power and Lossy Network (LLN). The red nodes are in an outage state, and their outage records need to be delivered to an outage server or the Border Router (BR). After experiencing an outage, a node usually remains up for a period of time (e.g., between tens of seconds and several minutes) depending on its super-capacity. It is a very challenging task to deliver so many PON messages to the BR outage server in such a short period of time. Nonetheless, timely delivery of PONs is important for power electric companies.

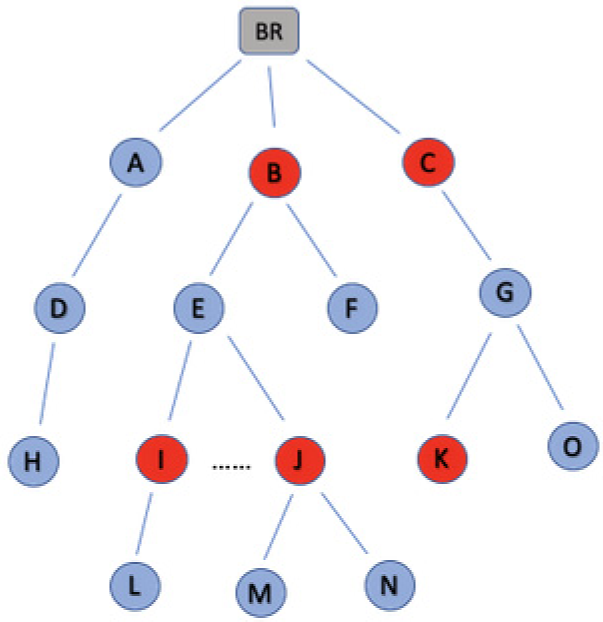

Figure 1

To solve this challenging task, techniques are described herein for timely delivery of PONs in LLNs. Briefly, irrelevant packets may be proactively prevented by broadcasting the PON alert to notify the surrounding nodes, and may also be filtered and discarded when a node is experiencing an outage. Multiple PON packets may be intelligently aggregated and compressed.

After experiencing an outage, a node usually remains up for a period of time (e.g., between tens of seconds and several minutes) depending on its super-capacity. These techniques provide timely delivery of PONs when outages occur. In particular, when an outage occurs, the node switches into a PON mode. When a node is in the PON mode, it sends a PON alert message in broadcast. The purpose is to notify its surrounding nodes (i.e., children, parent, and neighbors) that it is in PON mode and that therefore the surrounding nodes should not send any packets other than the PON packets. To save energy, when a node is in PON mode, it is only allowed to send and relay PON packets. All other packets are discarded. In some implementations, a flag may be set in PON packets or a special port may be allocated for the PON packets to enable the PON packets to be filtered.

In some implementations, the PON alert can be defined as a Destination-Oriented Directed Acyclic Graph (DODAG) Information Object (DIO) option and sent in DIO messages. As illustrated in Figure 2 below, outage nodes B, C, I, and J send DIO messages (with PON as a DIO option) to notify their surrounding nodes. When the surrounding nodes receive the DIO, they stop sending all packets other than PON packets.

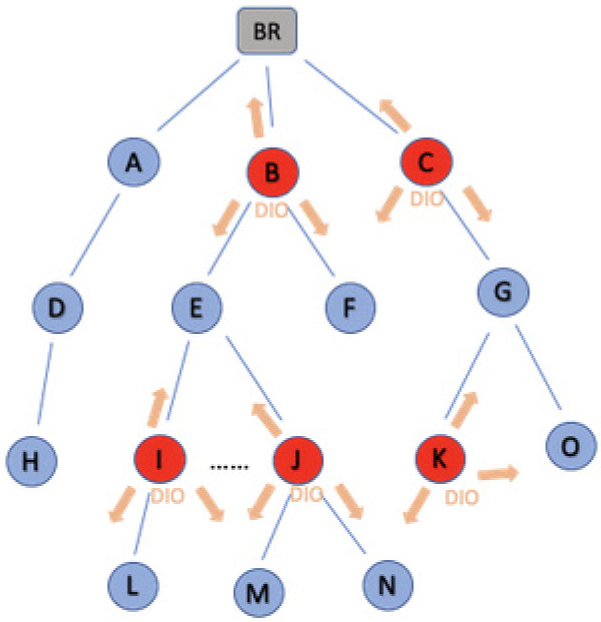

Figure 2

To further save energy, the PON packets may be aggregated. A node may wait for multiple (e.g., “X”) PON packets in a time period (e.g., “T” seconds), and send out the aggregated PON packets together. The number of aggregated PON packets X may be set according to the rank of the node. For example, if the rank is smaller, X may be bigger. T may be set according to the super-capacity and rank of the node. For example, if the super-capacity is bigger, then T is set longer. If the node’s rank is smaller, then T is set smaller.

If the number of aggregated PON packets reaches X, the aggregated packet may be sent in unicast to the BR (or outage server) directly. In Figure 3 below, for example, assume X = 8. In this example, node E aggregates eight PON packets from its children/descendants (e.g., nodes I, J, etc.), and sends the aggregated packet to the BR in unicast. Upon receiving the aggregated PON packet, node B may forward the aggregated PON packet to the BR without further aggregation.

In addition, if the number of aggregated PON packets does not reach X, but T seconds have passed, the aggregated packet may be sent in unicast to its parent for further aggregation. For example, in Figure 3, assume T = 5 and X = 8. Node K generates a PON packet and waits five seconds before sending the PON packet. The PON packet is sent to node G and then to node C for further aggregation. Node C aggregates the two PON packets together and sends them to the BR (outage server).

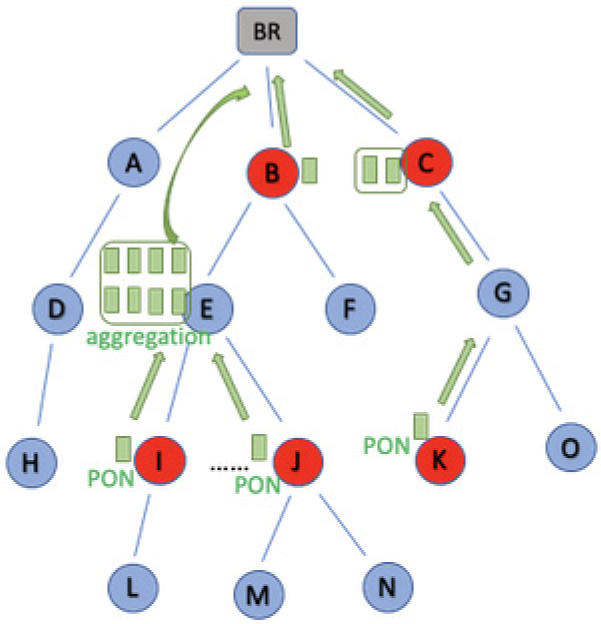

Figure 3

To save transmission time and energy, aggregated PON packets may be compressed. Figure 4 below illustrates an example original PON payload format. Here, N aggregated PON events are in one packet. The total length is N * (4 + 8) = 12N bytes.

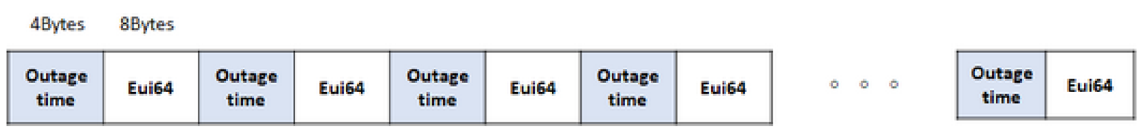

Figure 4

Figure 5 below illustrates an example compressed PON payload format. The base outage time represents the minimum outage time of all PON events. "Off" represents the offset between each PON event outage time and the base outage time. For example, consider a scenario where the base outage time is 100, the outage time of a first PON event is 120, the outage time of a second PON event is 130, and the outage time of a third PON event is 140. In this example, the offset associated with the first PON event is 20, the offset associated with the second PON event is 30, and the offset associated with the third PON event is 40. The PON event may be reported in a certain threshold (e.g., less than two minutes). As such, one byte (e.g., 256 seconds) may be sufficient to cover the range. As shown in Figure 5, the total length is 12 + (8 + 1) * (N - 1) = 9N + 3 bytes. If N = 30, 12N - 9N - 3 = 87 bytes may be saved.

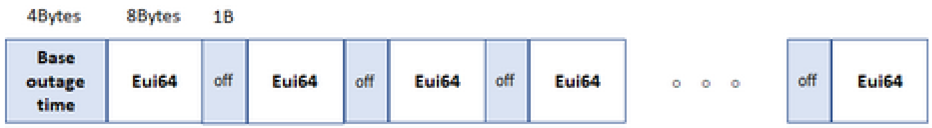

Figure 5

In summary, techniques are described herein to timely deliver PON messages when a power outage occurs in smart utilities. Irrelevant packets may be proactively prevented by broadcasting the PON alert to notify the surrounding nodes, and may also be filtered and discarded when a node is experiencing an outage. Multiple PON packets may be intelligently aggregated and compressed.